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[Article]

Physiological Response of Some Economically Important Freshwater Salmonids to Catch-and-Release Fishing

GARY A. WEDEMEYER*
U.S. Geological Survey, Western Fisheries Research Center, 6505 Northeast 65th Street, Seattle, Washington 98115, USA

RICHARD S. WYDOSKI[1]
U.S. Geological Survey, Utah Cooperative Fish and Wildlife Research Unit, Utah State University, Logan, Utah 84322, USA

Abstract.—Catch-and-release fishing regulations are widely used by fishery resource managers to maintain both the quantity and quality of sport fish populations. We evaluated blood chemistry disturbances in wild brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, cutthroat trout *Oncorhynchus clarkii*, and Arctic grayling *Thymallus arcticus* that had been hooked and played for 1–5 min in waters of the intermountain western United States. A hatchery stock of brown trout was included for comparison. To assess time needed for recovery, additional test groups were played for 5 min and then released into net-pens, where they were held for up to 72 h. The osmoregulatory and metabolic disturbances associated with catch-and-release fishing under the conditions we tested were minimal and judged to be well within normal physiological tolerance limits. In fish that were held for recovery, the blood chemistry alterations that did occur appeared to be related to stress from confinement in the net-pens. Our results confirm the results of previous studies, showing that prerelease air exposure and handling cause more physiological stress than does either hooking per se or playing time. Fishery managers must be aware of the differences in the perceptions, attitudes, and values of different societal groups, some of which feel that catch-and-release fishing should be banned because it is cruel to the animals. On the basis of brain anatomy, it seems highly unlikely that fish experience pain in the same manner as humans experience it, because fish lack a neocortex, the brain structure that enables the sensation of pain in higher vertebrates. However, independent of the neurobiological argument, our results indicate that under conditions similar to those tested, fish subjected to catch and release are neither suffering nor particularly stressed. Improved education programs about the relatively benign physiological effects of catch-and-release fishing as a fishery management practice would be beneficial to anglers and the nonfishing public alike.

Recreational fishing has long been an important outdoor activity enjoyed by the American public, and it is expected to increase in popularity in the future. In 2001, 28.9 million anglers fished 407 million d in freshwater habitats of the United States and contributed US\$21.3 billion (i.e., $\$21.3 \times 10^9$) to the national economy (U.S. Fish and Wildlife Service and U.S. Bureau of the Census 2002). Thus, freshwater fish populations are subjected to persistently heavy fishing pressure, and fish and wildlife conservation agencies must employ innovative regulations to sustain them (Murphy and Willis 1996; Ross 1997).

Catching and then releasing fish rather than harvesting them was first proposed as a conservation measure in the early 1800s, and the first estimates of hooking mortality in angler-caught fish were made in the early 1900s (Westerman 1932). Today, catch-and-release fishing regulations have become very important management tools for the conservation of overexploited fish populations (Wydoski 1979; Jiang et al. 2007). Even when regulations allow harvest of the fish, many anglers voluntarily release their catch. For example, up to 75% of anglers in Washington State reported that they released some of their salmonid catch of legal length, and up to 18% percent reported that they released all captured salmonids (Washington Department of Fish and Wildlife 1996).

Immediate mortality of fish subjected to catch-and-release fishing can be caused by physical hooking damage to vital organs, such as the gills or heart. Absent this, however, the physiological stress resulting from hooking, playing, and handling during release is also important. The intense struggling associated with catching, playing, and handling during release may result in metabolic and osmoregulatory disturbances that are known to impair fish physiological health and quality and may lead to delayed mortality due to

* Corresponding author: gary_wedemeyer@usgs.gov
[1] Present address: U.S. Fish and Wildlife Service, Division of Federal Aid, Post Office Box 25486, Denver Federal Center, Denver, Colorado 80225-0486, USA.

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increased susceptibility to infectious diseases, such as those caused by fungi *Saprolegnia* spp. (Gustaveson et al. 1991; Barton 1997).

It is important to understand how normal physiological processes in a variety of species are affected by angling practices in various environments. The present study was designed to assess the physiological tolerance of four economically important salmonids to the stress associated with hooking, playing, and release during the course of recreational fishing. Brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, cutthroat trout *Oncorhynchus clarkii*, and Arctic grayling *Thymallus arcticus* were caught on artificial flies or lures at selected study sites in the intermountain western United States, and their tolerance to the stress of hooking and playing was evaluated based on alterations in selected blood chemistry parameters used as indices.

Changes in blood chloride, glucose, osmolality, and total hemoglobin were the physiological indices of interest and were chosen to allow direct comparison of this study with our previous work on the effects of catch-and-release fishing on the secondary stress response of fishes (Wydoski et al. 1976; Gustaveson et al. 1991). Plasma osmolality, chloride, and blood hemoglobin measurements were used to assess osmoregulatory disturbances, gill ion exchange function, and hemoconcentration. Plasma glucose was used as an index of the generalized physiological stress response (Morgan and Iwama 1997). Catecholamine and corticosteroid hormones involved in the primary stress response were not of direct interest. Tricaine methanesulfonate (MS-222) anesthesia was used because short-term treatment with this agent does not significantly change the blood chemistry of fish (MacAvoy and Zaepfel 1997).

Methods

The four salmonids tested (brook, brown, and cutthroat trouts and Arctic grayling) were captured by hook and line using artificial flies or lures between June and October at selected study sites, primarily located in high mountain lakes and reservoirs of the intermountain western United States (Table 1). A wild brown trout population in the Blacksmith Fork River, Utah, was sampled at the mouth of the canyon just before the river enters an agricultural area. A hatchery stock of brown trout was maintained in raceways supplied by well water at the Utah Division of Wildlife Resources (UDWR) Fisheries Experiment Station, Logan.

The fish that were hooked and played in Utah lakes and reservoirs and the brown trout studied at the UDWR Fisheries Experiment Station were caught by use of flies tied on size-10 and size-12 hooks. Brown trout in the Blacksmith Fork River were caught on number-1 (Mepps) spinners with size-8 treble hooks. Cutthroat trout in Yellowstone Lake, Wyoming, were caught on small wobbling spoons with size-6 treble hooks.

Fish from all populations were played for 0 (i.e., landed within 15 s), 1, 2, 3, 4, or 5 min; 5 min was believed to be the maximum duration for which small salmonids are normally played by recreational anglers. All fish were required to resist rod pressure during capture. If a fish became quiet, the rod tip was lifted to stimulate continued activity. None of the fish used in the study were played to exhaustion or hooked in vital areas (e.g., gills or heart).

Landed fish were immediately transferred to an aerated solution of 100 mg of MS-222/L of water. Air exposure during transfer was held to less than 10 s. Blood samples were drawn from the caudal vessels using heparinized syringes. Hemoglobin was measured in the field using a Bausch & Lomb optical hemoglobinometer. Plasma was then separated quickly by centrifugation and frozen on dry ice for later chemical analyses via the methods recommended by Morgan and Iwama (1997).

To obtain information on the time needed by fish to recover from catch-and-release fishing, the fish were hooked and played for 5 min, released into aerated tanks, and quickly transported by boat to nearby net-pens, where they were held for up to 72 h. To minimize crowding stress, the net-pens were sized to maintain a fish loading density of 1.4 kg/m^3 or less (Wedemeyer 1996). To minimize sampling stress, the procedures employed in our previous work on catch-and-release fishing were followed (Wydoski et al. 1976; Gustaveson et al. 1991). Blood samples were taken from the net-pen groups after 1, 2, 4, 8, 24, 48, or 72 h. The target sample size was 10 fish/group. However, this sample size could not always be achieved, as sufficient numbers of fish were not always caught.

The blood chemistry data were analyzed using an unpaired Student's *t*-test (SPSS 1997). The significance level for all tests was 0.05.

Results

Mean fork length ranged from 212 mm for brook trout from Ibantek Reservoir to 369 mm for cutthroat trout from Yellowstone Lake. Regression equations are provided to allow estimation of mean total lengths from fork lengths (Table 1). Water temperatures were 10–17°C, which are normal summer temperatures at higher elevations in the intermountain western United States (Table 2). All waters sampled were neutral to slightly alkaline (pH = 7.0–8.6).

Baseline (Control) Blood Chemistry Data

When blood chemistry changes are used to evaluate physiological stress in wild fish populations, it is

TABLE 1.—Mean (±SE) fork length (FL, mm) of salmonids caught by hook and line for an evaluation of fish physiological tolerance to hooking stress in various systems of Wyoming (WY) and Utah (UT). Regression equations for converting FL to total length (TL, mm) are given for selected species.

Species and location	Sample size	FL (mm)	FL–TL regression: Equation	FL–TL regression: *r*
Cutthroat trout				
Yellowstone Lake, Wyoming	191	363.8 ± 1.9	TL = 1.01(FL) + 13.98	0.978
Sheep Creek Reservoir, Utah	81	287.6 ± 3.0	TL = 1.03(FL) + 3.53	0.994
Woodruff Reservoir, Utah	61	257.2 ± 4.3	TL = 1.03(FL) − 7.90	0.999
Brook Trout				
Ibantek Reservoir, Utah	49	212.1 ± 2.6		
White Pine Lake, Utah	59	231.2 ± 3.6	TL = 1.02(FL) + 4.31	0.997
Brown Trout				
Blacksmith Fork River, Utah	63	234.0 ± 6.9	TL = 0.99(FL) + 8.38	0.999
Fisheries Experiment Station, Utah	120	265.0 ± 2.1		
Arctic Grayling				
Sand Lake, Utah	100	265.0 ± 2.2		

helpful to have estimates of the normal range so that abnormal values can be recognized. Such information is generally lacking for the wild salmonid species we tested. As a first approximation, we used blood chemistry values from fish landed within 15 s as the baseline (Table 2). Although the blood chemistry of wild and hatchery fish can be affected by environmental conditions, diet, or genetic strain, the baseline values for the tested populations were generally within the range of previously published data for hatchery salmonids (Wedemeyer 1996).

Baseline Chloride

The mean baseline plasma chloride level ranged from 110.6 to 126.8 milliequivalents (mEq)/L in cutthroat trout, brook trout, brown trout, and Arctic grayling (playing time = 0 min; Table 2). This is within the range reported for other salmonids (Wedemeyer 1996). Arctic grayling had the lowest blood chloride level (mean = 110.6 mEq/L), and Woodruff Reservoir cutthroat trout had the highest level (126.8 mEq/L). The baseline plasma chloride level for brook trout from Ibantek Reservoir was 111.6 mEq/L, very similar to the

TABLE 2.—Water temperature (temp) at capture and baseline blood chemistry levels (mean ± SE; sample size is given in parentheses; mEq = milliequivalents; mOsm = milliosmoles) measured in test salmonids used as controls (i.e., hooked and landed within 15 s; 0 min of playing time) in a study of fish physiological tolerance to hooking stress in various systems of Wyoming and Utah (see Table 1 for the location of each system).

Species and location	Temp (°C)	Chloride (mEq/L)	Glucose (mg/100 mL)	Osmolality (mOsm/L)	Hemoglobin (g/100 mL)
Cutthroat trout					
Yellowstone Lake	10–11	120.0 ± 1.4 (20)	72.0 ± 4.0 (20)	260.0 ± 7.1 (20)	7.2 ± 0.2 (20)
Sheep Creek Reservoir	13–15	124.1 ± 2.3 (15)	91.7 ± 4.4 (15)	314.0 ± 4.3 (4)	8.4 ± 0.4 (15)
Woodruff Reservoir	12–13	126.8 ± 4.5 (10)	82.1 ± 8.1 (10)	284.1 ± 2.0 (10)	7.6 ± 0.2 (10)
Brook trout					
Ibantek Reservoir	11–13	111.6 ± 2.0 (5)	38.3 ± 6.9 (5)	267.8 ± 16.9 (5)	8.9 ± 0.9 (5)
White Pine Lake	12–13	125.1 ± 3.0 (5)	72.0 ± 5.9 (7)	298.0 ± 3.0 (5)	7.5 ± 0.3 (7)
Brown trout					
Blacksmith Fork River	14–16	118.0 ± 3.3 (9)	68.4 ± 2.5 (9)	284.8 ± 4.7 (8)	6.6 ± 0.2 (10)
Fisheries Experiment Station	17	113.6 ± 1.6 (10)	82.1 ± 8.9 (9)	305.6 ± 3.5 (10)	9.5 ± 0.4 (10)
Arctic grayling					
Sand Lake	12–13	110.6 ± 2.4 (10)	80.3 ± 9.2 (10)		8.0 ± 0.3 (10)

TABLE 3.—Effect of catch-and-release fishing on mean blood chloride level (milliequivalents [mEq]/L; SE is in parentheses; sample size is given below SE) in test salmonids that were hooked and played for 0–5 min during a study of fish physiological tolerance to hooking stress in various systems of Wyoming and Utah (see Table 1 for the location of each system). Some fish that were played for 5 min were also released into net-pens and monitored during a 72-h holding period (*$P < 0.05$, significant difference from baseline).

	Playing time (min)						Holding time (h)						
Species and location	0	1	2	3	4	5	1	2	4	8	24	48	72
Cutthroat trout													
Yellowstone Lake	120.0	122.0	124.2*	122.6	125.0*	124.2*	121.2	121.6	115.8*	111.3*	110.0*	114.8*	112.0*
	(1.4)	(1.5)	(1.5)	(1.6)	(1.2)	(1.7)	(1.9)	(1.4)	(2.5)	(1.4)	(3.0)	(2.8)	(2.4)
	20	20	20	19	20	20	9	10	9	10	9	10	10
Sheep Creek Reservoir	124.1	120.0	113.2*	127.2	112.8*	122.3	116.0*		108.6*	102.6*	105.3*	97.3*	121.0
	(2.3)	(2.2)	(2.9)	(3.1)	(5.1)	(4.6)	(4.5)		(5.6)	(5.1)	(4.1)	(0.8)	(6.5)
	15	4	5	5	5	6	8		7	7	8	6	4
Woodruff Reservoir	126.8	128.4	127.2	124.4	123.6	128.8	122.6			106.8*	121.6	116.4	124.4
	(4.5)	(2.3)	(4.0)	(1.6)	(2.4)	(1.5)	(3.4)			(2.1)	(4.0)	(8.5)	(5.0)
	10	5	5	5	5	5	6			5	5	5	5
Brook trout													
Ibantek Reservoir	111.6	112.4	111.6	112.0	115.2*	111.2		111.0		114.0	104.6*	114.8	116.0
	(2.0)	(5.7)	(0.9)	(2.0)	(1.4)	(3.1)		(3.1)		(2.6)	(1.3)	(1.9)	(4.5)
	5	5	5	4	5	6		4		5	5	5	4
White Pine Lake	125.1	132.1	126.0	124.4	117.7	132.7	128.4			118.4*	114.0*	110.4*	111.5*
	(3.0)	(8.8)	(3.0)	(2.4)	(3.7)	(2.88)	(4.1)			(1.3)	(2.2)	(4.8)	(1.7)
	5	5	5	6	6	5	5			5	4	5	4
Brown trout													
Blacksmith Fork River	118.0	126.6	123.0	125.1	124.2	124.6							
	(3.3)	(3.1)	(1.6)	(2.2)	(2.3)	(2.0)							
	9	10	10	9	10	10							
Fisheries Experiment Station	113.6	118.4*	116.4	108.0*	110.6	114.0	116.5	106.5	108.4*	105.6*	105.4*	109.9*	103.2*
	(1.6)	(1.2)	(1.3)	(1.7)	(2.3)	(1.5)	(2.0)	(1.6)	(1.8)	(2.0)	(1.4)	(1.1)	(2.6)
	10	10	10	10	10	10	10	8	9	10	9	10	10
Arctic grayling													
Sand Lake	110.6	103.6*	100.8*	95.8*	101.6*	108.2		99.8*		99.0*	100.2*	98.6*	100.8*
	(2.4)	(1.7)	(1.6)	(3.1)	(3.7)	(2.1)		(3.2)		(3.1)	(2.7)	(3.3)	(3.2)
	10	10	10	10	10	10		9		10	8	10	10

110 mEq/L reported for hatchery-reared brook trout by McDonald et al. (1993). Hatchery and wild stocks of brown trout had similar plasma chloride values (113.6 and 118.0 mEq/L, respectively).

Baseline Glucose

Mean baseline blood glucose ranged from 38.3 to 91.7 mg/100 mL among tested species (Table 2). The lowest blood glucose value (mean = 38.3 mg/100 mL) occurred in the Ibantek Reservoir brook trout population; the highest value was observed in Sheep Creek Reservoir cutthroat trout (91.7 mg/100 mL). Baseline glucose was higher in the hatchery brown trout (82.1 mg/100 mL) than in the wild stock (68.4 mg/100 mL), as might be expected based on dietary considerations.

Baseline Osmolality

Baseline plasma osmolality ranged from 260.0 to 314.0 milliosmoles (mOsm)/L in cutthroat trout, brook trout, and brown trout (Table 2; osmolality was not measured in Arctic grayling). Both the high and low values were observed for cutthroat trout populations. Blood osmolality was higher in hatchery brown trout (305.6 mOsm/L) than in wild brown trout (284.8 mOsm/L).

Baseline Hemoglobin

Mean blood hemoglobin ranged from 6.6 to 9.5 mg/100 mL in the study populations (Table 2) and was well within the normal range reported for hatchery salmonids. Blood hemoglobin was higher in hatchery brown trout (9.5 mg/100 mL) than in wild brown trout (6.6 mg/100 mL); again, the difference was presumably because of diet composition.

Effects of Hooking and Playing on Chloride

Blood chloride disturbances caused by hooking and playing differed somewhat among the tested salmonid populations but were generally mild (Table 3). The Sheep Creek Reservoir cutthroat trout exhibited mild hypochloremia when played 1–5 min; even though mean values at 2 and 5 min were statistically significant, this degree of blood chloride loss was judged unlikely to be physiologically challenging. Blood chloride levels in Yellowstone Lake and Woodruff Reservoir cutthroat trout either exhibited no change or increased slightly as playing time increased.

The blood chloride level in the two brook trout populations remained almost unchanged when these fish were played for 1–5 min. Although statistically significant, the hyperchloremia at 4 min of playing time in Ibantek Reservoir fish was small and judged to be of little physiological consequence. Wider fluctuations occurred in White Pine Lake brook trout, but none of the values were significantly different from the baseline.

Hooking and playing produced no significant effects on blood chloride levels in wild brown trout. Hatchery brown trout exhibited transient hyperchloremia at 1 min of playing time and transient hypochloremia at 3 min. However, blood chloride values at 2, 4, and 5 min of playing time remained near the baseline level.

Arctic grayling suffered significant initial hypochloremia in response to hooking; by 3 min, blood chloride approached the 90-mEq/L level that is considered to be life threatening in other salmonids (Wedemeyer 1996). However, the effect was transient, and blood chloride recovered to near baseline in fish played for 5 min.

Effects of Hooking and Playing on Glucose

Hooking and playing effects on plasma glucose level were generally mild in the fish populations tested, although some species-specific differences did occur (Table 4). Yellowstone Lake cutthroat trout exhibited hyperglycemia only after being hooked and played for 5 min, whereas Sheep Creek cutthroat trout reacted more quickly, after only 2 min. Blood glucose values in cutthroat trout from Woodruff Reservoir were unaffected by hooking and playing.

Brook trout from Ibantek Reservoir suffered immediate hyperglycemia beginning at 1 min of playing time; glucose level in White Pine Lake brook trout was unaffected by the duration of playing. Hooking and playing caused no significant effects on blood glucose in wild or hatchery brown trout. As playing time increased, blood glucose in Arctic grayling fluctuated significantly downward, perhaps a reflection of the vigorous muscle exertion exhibited by these fish.

Effects of Hooking and Playing on Osmolality

There were no significant differences in plasma osmotic pressure (osmolality) in any of the three cutthroat trout populations tested, indicating that catch-and-release fishing had little effect on their fluid balance (Table 5). The two brook trout populations and the hatchery and wild brown trout were similarly refractory.

Effects of Hooking and Playing on Hemoglobin

Hooking and playing for 1–5 min had little effect on blood hemoglobin in any of the tested populations (Table 6). Significant differences were observed at 2 min of playing time for Yellowstone Lake cutthroat trout and wild brown trout, but these differences were transient and probably of little physiological consequence.

Blood Chemistry during Net-Pen Holding

To evaluate the time required for the fish to recover from any physiological effects of catch-and-release fishing, cutthroat trout, brook trout, hatchery brown trout, and Arctic grayling were played for 5 min and then released into net-pens for up to 72 h. Blacksmith Fork River brown trout could not be held in net-pens because the river was too shallow.

Although the loading density we used (<1.4 kg/m^3) was light by hatchery standards, confinement stress in the net-pens was quite evident and biased the results on time to recovery. The incidence of abrasions on the snouts of fish held in net-pens increased over time, indicating that the fish were seeking a way out. Since physiological stress in fish is nonspecific and cumulative (Barton 1997), it is difficult to separate changes in blood chemistry due to delayed effects of hooking and playing from those due to confinement stress. Thus, we could obtain only a rough estimate of the recovery time needed by fish released into the wild after being hooked, played, and handled.

Chloride during Holding

In cutthroat trout from Yellowstone Lake, hypochloremia became evident after only a few hours in the net-pens, and blood chloride levels were still low at 72 h (Table 3). However, Sheep Creek cutthroat trout recovered to near-baseline levels by 72 h, and Woodruff Reservoir cutthroat trout were largely unaffected. The brook trout populations also exhibited different patterns of hypochloremia during net-pen holding. Ibantek Reservoir brook trout were relatively unaffected by confinement but did exhibit transient hypochloremia after being held for 24 h. In contrast, White Pine Lake brook trout suffered prolonged hypochloremia that was still evident at 72 h (Table 3).

Hatchery brown trout suffered persistent hypochloremia during the entire 72-h holding period (Table 3). Arctic grayling also exhibited persistent hypochloremia when released into the net-pens, although blood chloride values remained above the 90-mEq/L level considered life threatening in other salmonids (Wedemeyer 1996).

TABLE 4.—Effect of catch-and-release fishing on mean blood glucose level (mg/100 mL; SE is in parentheses; sample size is given below SE) in test salmonids that were hooked and played for 0–5 min during a study of fish physiological tolerance to hooking stress in various systems of Wyoming and Utah (see Table 1 for the location of each system). Some fish that were played for 5 min were also released into net-pens and monitored during a 72-h holding period (*$P < 0.05$, significant difference from baseline).

	Playing time (min)						Holding time (h)						
Species and location	0	1	2	3	4	5	1	2	4	8	24	48	72
Cutthroat trout													
Yellowstone Lake	72.0	66.0	73.0	71.9	74.7	85.3*	97.4*	73.1*	107.1*	133.1*	116.6*	137.4*	114.1*
	(4.0)	(3.0)	(3.1)	(2.4)	(3.1)	(4.8)	(7.1)	(5.3)	(7.9)	(10.4)	(11.8)	(8.0)	(8.3)
	20	20	20	19	20	20	10	10	9	9	10	10	10
Sheep Creek Reservoir	91.7	99.5	111.8*	93.7	103.1*	104.2*	139.6*		159.1*	230.2*	188.1*	141.9*	99.8
	(4.4)	(7.3)	(10.3)	(7.1)	(5.9)	(7.0)	(6.2)		(25.4)	(35.3)	(32.2)	(17.2)	(19.6)
	15	4	5	5	5	6	8		7	7	8	6	4
Woodruff Reservoir	82.1	68.4	65.1	77.8	71.2	69.2	119.6*			124.9*	140.0*	163.6*	121.7*
	(8.1)	(5.0)	(4.0)	(3.0)	(4.2)	(3.7)	(4.4)			(17.6)	(19.1)	(34.4)	(12.5)
	10	5	5	5	5	5	6			5	5	5	5
Brook trout													
Ibantek Reservoir	38.3	70.0*	66.2*	70.3*	75.7*	63.3*		134.5*		158.1*	181.7*	117.1*	121.8*
	(6.9)	(5.4)	(5.8)	(5.3)	(4.9)	(5.1)		(23.6)		(6.5)	(23.5)	(8.2)	(11.0)
	5	5	5	4	5	6		4		5	5	5	4
White Pine Lake	72.0	80.0	90.9	81.2	73.7	89.6	130.7*			130.8*	150.5*	148.8*	159.2*
	(5.9)	(5.5)	(8.4)	(9.8)	(7.7)	(3.3)	(7.3)			(16.8)	(14.7)	(29.8)	(15.3)
	7	5	5	5	6	6	5			5	4	4	4
Brown trout													
Blacksmith Fork River	68.4	71.7	75.6	66.9	68.8	74.3							
	(2.5)	(2.5)	(2.3)	(1.9)	(2.1)	(2.7)							
	9	10	10	9	10	10							
Fisheries Experiment Station	82.1	75.4	68.9	72.1	76.6	78.3	112.0*	103.1	132.9*	126.9*	104.4*	116.6*	110.9*
	(8.9)	(8.6)	(2.9)	(5.2)	(6.4)	(4.7)	(10.4)	(13.9)	(11.4)	(9.6)	(8.4)	(8.1)	(13.5)
	9	10	10	9	10	10	10	9	9	10	10	10	10
Arctic grayling													
Sand Lake	80.3	80.1	68.2	57.8*	84.2	62.2*		117.9*		130.0*	126.7*	111.7*	108.2*
	(9.2)	(3.2)	(3.0)	(3.2)	(2.8)	(5.9)		(11.2)		(7.8)	(8.9)	(8.1)	(8.1)
	10	10	10	10	10	10		9		10	8	10	10

Glucose during Holding

In Yellowstone Lake cutthroat trout, plasma glucose remained persistently elevated during net-pen holding, thus continuing the hyperglycemia that developed after 5 min of playing time (Table 4). In Sheep Creek Reservoir cutthroat trout, hyperglycemia developed after only 2 min of playing and worsened during the first 8 h of net-pen holding. By 72 h, however, these fish had nearly recovered to 99.8 mg/100 mL, which was not significantly different from the baseline level. Although hooking and playing caused no significant effect on blood glucose in Woodruff Reservoir cutthroat trout, these fish developed significant hyperglycemia during holding, which indicated a reaction to net-pen confinement.

In Ibantek Reservoir brook trout, plasma glucose levels increased significantly during the first 24 h of net-pen holding, continuing the hyperglycemia that was detected at 1 min of playing; at 48 and 72 h, glucose declined somewhat. However, the glucose level at 72 h (121.8 mg/100 mL) was still quite high relative to the baseline (38.3 mg/100 mL). In contrast, White Pine Lake brook trout suffered significant hyperglycemia at all observation times during the 72-h holding period but not at 1–5 min of playing. The final blood glucose level for White Pine Lake fish (159.2 mg/100 mL) was more than double the baseline value (72.0 mg/100 mL).

Hatchery brown trout suffered no significant effects on blood glucose during hooking and playing for 0–5 min. However, mild but persistent hyperglycemia that was indicative of chronic stress also developed when these fish were released into the net-pens and held for recovery testing (Table 4). In Arctic grayling, blood glucose increased significantly during the first few hours in the net-pens and was still high at 72 h.

Osmolality during Holding

Plasma osmolality fluctuated somewhat after Yellowstone Lake cutthroat trout were played for 5 min and released into the net-pens, but no significant changes occurred (Table 5). However, Sheep Creek cutthroat trout suffered a significant osmotic pressure decrease by 24 h, and osmolality was still low at 72 h. Woodruff Reservoir cutthroat trout suffered low

TABLE 5.—Effect of catch-and-release fishing on mean blood osmolality (milliosmoles [mOsm]/L; SE is in parentheses; sample size is given below SE) in test salmonids that were hooked and played for 0–5 min during a study of fish physiological tolerance to hooking stress in various systems of Wyoming and Utah (see Table 1 for the location of each system; osmolality was not measured in Arctic grayling from Sand Lake). Some fish that were played for 5 min were also released into net-pens and monitored during a 72-h holding period (*$P < 0.05$, significant difference from baseline).

Species and location	Playing time (min)						Holding time (h)						
	0	1	2	3	4	5	1	2	4	8	24	48	72
Cutthroat trout													
Yellowstone Lake	260.0	270.6	277.1	273.5	269.9	277.9	272.1	282.0	270.5	240.1	246.3	248.7	220.4
	(7.1)	(5.9)	(5.8)	(6.9)	(6.4)	(8.1)	(13.3)	(8.6)	(5.8)	(9.9)	(8.8)	(10.7)	(10.3)
	20	17	20	19	17	20	10	9	10	9	8	10	9
Sheep Creek Reservoir	314.0	321.7	311.0	325.0	318.2	330.2	325.5	328.5	328.5	319.5	280.5*	318.7	291.0*
	(4.3)	(3.6)	(6.6)	(14.1)	(5.7)	(5.9)	(7.6)	(4.3)	(4.3)	(14.2)	(14.5)	(2.3)	(1.0)
	4	3	3	4	5	6	4	4	4	4	4	3	2
Woodruff Reservoir	281.1	280.8	281.0	292.2	280.6	290.5	291.7			244.8*	282.5	277.7	285.1
	(2.0)	(4.8)	(5.3)	(2.6)	(5.0)	(4.9)	(5.5)			(3.2)	(5.8)	(12.9)	(8.5)
	10	5	5	5	5	5	6			5	5	5	5
Brook trout													
Ibantek Reservoir	267.8	244.4	251.8	257.8	234.8	266.6		273.0		248.3	222.5	270.0	267.7
	(16.9)	(11.2)	(4.5)	(12.6)	(18.8)	(13.4)		(5.0)		(10.8)	(13.7)	(4.0)	(13.6)
	5	5	4	4	5	5		2		4	4	2	3
White Pine Lake	298.0	313.4	312.8	300.8	286.0	308.3	316.8			304.8	258.5*	288.2*	273.8*
	(3.0)	(8.8)	(3.0)	(2.4)	(3.7)	(2.8)	(4.1)			(1.3)	(2.2)	(4.8)	(1.7)
	7	5	5	5	6	6	5			5	4	5	4
Brown trout													
Blacksmith Fork River	284.8	300.1	298.8	303.8	304.7	305.8							
	(4.7)	(2.4)	(3.2)	(2.8)	(2.5)	(3.0)							
	8	9	10	9	10	10							
Fisheries Experiment Station	305.6	300.8	303.7	293.6	298.9	305.1	321.3*	312.6	308.8	294.8	288.6*	295.8	288.7*
	(3.5)	(4.6)	(4.3)	(2.5)	(4.9)	(5.0)	(5.2)	(3.9)	(4.7)	(5.3)	(3.1)	(4.7)	(3.9)
	10	10	10	10	10	10	9	10	10	10	7	10	9

osmotic pressure after only 8 h in the net-pens, but osmolality recovered by 24 h (Table 5).

Osmolality in brook trout from Ibantek Reservoir was unaffected by the 72-h net-pen holding period, but White Pine Lake fish exhibited a significant hypo-osmolar condition at 24 h (Table 5). Plasma osmolality in the hatchery stock of brown trout increased significantly over the baseline value during the first hour in the net-pens but then declined steadily during the remainder of the holding period (Table 5). Effects on blood osmolality were not evaluated in Arctic grayling.

Hemoglobin during Holding

In cutthroat trout from Yellowstone Lake and Sheep Creek Reservoir, the blood hemoglobin concentration began increasing after only 1 h in the net-pens and remained significantly elevated thereafter, suggesting that some degree of hemoconcentration was occurring (Table 6). The hemoglobin level in Woodruff Reservoir cutthroat trout was unaffected. Net-pen holding also had no significant effect on blood hemoglobin concentration in the two brook trout populations. In hatchery brown trout, hemoglobin was significantly higher after 8 and 24 h of net-pen holding but then recovered to baseline. Blood hemoglobin was significantly elevated in Arctic grayling during net-pen holding, again indicative that some degree of hemoconcentration had occurred.

Discussion

In general, the exertion associated with hooking and playing for up to 5 min caused only minor alterations in osmoregulation and metabolism in cutthroat trout, brook trout, brown trout, and Arctic grayling. It is noteworthy that net-pen confinement did cause physiological indications of stress in these fish. Thus, the blood chemistry indices we employed were adequately sensitive to detect any physiological stress caused by the tested hooking and playing procedures.

Ionoregulation in these species was little affected by hooking and playing, as indicated by relatively stable plasma chloride and osmolality values. Only Arctic grayling developed frank hypochloremia. Transient hyperchloremia, which occurred in Yellowstone Lake cutthroat trout and Ibantek Reservoir brook trout, was also noted in our earlier catch-and-release studies of hatchery and wild rainbow trout *O. mykiss* and largemouth bass *Micropterus salmoides* (Wydoski et al. 1976; Gustaveson et al. 1991).

Although hooking and playing had no significant effect on blood osmotic pressure in our study animals,

TABLE 6.—Effect of catch-and-release fishing on mean blood hemoglobin level (mg/100 mL); SE is in parentheses; sample size is given below SE) in test salmonids that were hooked and played for 0–5 min during a study of fish physiological tolerance to hooking stress in various systems of Wyoming and Utah (see Table 1 for the location of each system). Some fish that were played for 5 min were also released into net-pens and monitored during a 72-h holding period (*$P < 0.05$, significant difference from baseline).

	Playing time (min)						Holding time (h)						
Species and location	0	1	2	3	4	5	1 hr	2	4	8	24	48	72
Cutthroat trout													
Yellowstone Lake	7.2	7.4	7.8*	7.5	7.1	7.6	9.1*		8.9*	9.8*	10.1*	9.8*	10.3*
	(0.2)	(0.2)	(0.2)	0.2	(0.3)	(0.2)	(0.3)		(0.4)	(0.3)	(0.3)	(0.2)	(0.5)
	20	20	20	20	20	20	10		10	9	9	10	10
Sheep Creek Reservoir	8.4	8.7	8.9	9.3	8.7	6.9	9.4*		8.8	10.0*	9.9*	9.9*	9.5*
	(0.4)	(0.3)	(0.5)	(0.9)	(0.6)	(0.6)	(0.2)		(0.5)	(0.6)	(0.6)	(0.4)	(0.5)
	15	4	5	5	5	6	8		7	7	8	6	4
Woodruff Reservoir	7.6	7.9	8.4	8.9	9.1	8.3	7.9			8.5	9.4	8.9	9.3
	(0.2)	(0.3)	(0.2)	(0.3)	(0.7)	(0.5)	(0.5)			(0.5)	(0.4)	(0.3)	(0.2)
	10	5	5	5	5	5	6			5	5	5	5
Brook trout													
Ibantek Reservoir	8.9	8.3	7.0*	8.5	8.5	9.3				8.5	8.4	9.0	8.3
	(0.9)	(0.6)	(0.3)	(0.4)	(0.5)	(0.3)				(0.3)	(0.4)	(0.3)	(0.3)
	5	5	5	4	5	6				5	5	5	4
White Pine Lake	7.5	8.0	7.4	8.4	7.6	8.2	8.8			8.6	9.1	9.0	9.1
	(0.3)	(0.2)	(0.2)	(0.5)	(0.5)	(0.2)	(0.2)			(0.4)	(0.5)	(0.5)	(0.9)
	7	5	5	5	6	6	5			5	5	5	5
Brown trout													
Blacksmith Fork River	6.6	6.3	7.1	7.3	8.1	8.0							
	(0.2)	(0.3)	(0.2)	(0.4)	(0.4)	(0.3)							
	10	10	10	12	11	10							
Fisheries Experiment Station	9.5	9.1	8.5	7.9	8.6	8.6	8.8		8.8	9.7*	9.6*	9.4	9.1
	(0.4)	(0.2)	(0.3)	(0.9)	(0.9)	(0.3)	(0.3)		(0.6)	(0.4)	(0.4)	(0.6)	(0.5)
	10	10	10	10	10	10	10		10	10	10	10	10
Arctic grayling													
Sand Lake	8.0	8.5	8.3	8.0	8.2	8.2				9.0*	9.3*	9.2*	9.8*
	(0.3)	(0.2)	(0.2)	(1.0)	(0.4)	(0.2)				(0.2)	(0.2)	(0.4)	(0.4)
	10	10	10	10	10	10				10	10	10	10

a significant increase in osmolality with playing time was reported for hooked and played largemouth bass (Gustaveson et al. 1991) and striped bass *Morone saxatilis* (Tomasso et al. 1996). Such changes in osmotic pressure in exercised fish are usually interpreted as being caused by ion concentration changes due to fluid shifts between extracellular and intracellular compartments (Wood 1991). The osmolality deficit and progressive hypochloremia measured after the test fish were released into net-pens can probably be explained as some combination of ion loss across the gills, diuretic ion loss, and hemodilution due to the net influx of water through the gills. Of these, increased branchial efflux of the chloride ion has been judged to be the most important (McDonald and Milligan 1997). Inorganic ions (mainly sodium and chloride) are considered to account for most of the plasma osmolality in fishes (Wedemeyer 1996).

Hooking and playing caused persistent hyperglycemia in only the Ibantek Reservoir brook trout. The other species were refractory, except for Arctic grayling, which suffered unexplained hypoglycemia that was possibly due liver and muscle glycogen levels being insufficient to maintain blood glucose during vigorous muscle exertion. Hatchery rainbow trout that were hooked and played for 30–60 s at water temperatures comparable to those used here (9–14°C) also exhibited no blood glucose effect (Wedekind and Schreckenback 2003). Similarly, no glucose effect was observed in striped bass that were hooked and played in freshwater during winter, when water temperatures were 16–19°C (Tomasso et al. 1996).

Blood hemoglobin in the tested populations was generally little affected by hooking and playing. Exceptions occurred at 2 min for Yellowstone Lake cutthroat trout and Ibantek Reservoir brook trout, but we do not believe this degree of change has physiological consequences. The hemoglobinemia that occurred after release into the net-pens was mild and resulted from confinement stress. In previous work on handling stress and muscle exertion, hemoglobinemia attributed to hemoconcentration has generally been noted, even though increased water uptake due to increased gill perfusion may also occur (Wedemeyer 1996). The observed hemoglobinemia can probably be accounted for by the movement of water from blood to tissues, thereby causing osmolality and hemoglobin concentrations to increase despite the increased water uptake through the gills (Gustaveson et al. 1991). However, no single explanation has been found, and adrenergic mediated splenic contraction is another possible contributor (Gallaugher and Farrell 1998).

Significant delayed mortality due to blood CO_2 retention has been documented in rainbow trout exposed to air for 60 s after a 10-min bout of exercise that simulated playing to exhaustion (Ferguson and Tufts 1992). Booth et al. (1995) found that wild Atlantic salmon *Salmo salar* that were caught, played to exhaustion, and released suffered no mortality if air exposure was brief (5 s). Other studies also indicate that exhaustive exercise due to catch-and-release fishing is not necessarily associated with significant mortality (Barnhardt 1989; Tufts et al. 1991; Pope et al. 2007). In the present work, air exposure was limited to 10 s or less and postangling mortality did not occur except for a single Arctic grayling that died from no apparent cause immediately after it was landed.

When a fish is hooked by an angler, it typically responds with rapid swimming behavior (flight response). It seems intuitive to many people that if fish react to nociceptive stimuli that would cause a human to feel pain, the fish must also be experiencing pain; this feelings-based philosophical stance is termed anthropomorphism (Arlinghaus et al. 2007).

Teleosts and elasmobranchs have the simplest vertebrate brains and lack a neocortex, the anatomical system that enables mammals to be conscious of sensory stimuli and to feel pain (Rose 2002). Simply put, fish lack the neocortical development that is necessary to experience the psychological occurrence of suffering or the unpleasant sensation of pain as humans know it (Rose 2007). Fish responses to nociceptive stimuli are escape and avoidance behaviors that are generated automatically at the brainstem and spinal cord levels. There is no evidence that fish have conscious awareness of the neural activity that is occurring. This point is important because some opponents of fishing have argued that although a neocortex is lacking, fish can still feel pain due to the presence of some of the lower, subcortical nervous system pathways used for nociception. However, all shark species that have been studied lack nociceptors (Snow et al. 1993), yet they react to hooking and playing in the same vigorous manner as do teleost fishes. In addition, tagging studies have shown that fish caught and released by anglers are often soon recaptured by other anglers, occasionally multiple times (Burkett et al. 1986).

Although the test fish did not have the neocortex development necessary to experience humanlike pain or suffering, their nonconscious reactions to nociceptive stimuli are still important because such reactions can potentially elicit a physiological stress response and accompanying behavioral alterations (Schreck et al. 1997; UFR 2004; Iwama 2007). The relative absence of clinical signs of the secondary stress response in our study is another indication that catch-and-release fishing is not unduly deleterious to the tested salmonids.

Fishery managers must be aware of the differences in the perceptions, attitudes, and values of different societal groups, some of which feel that catch-and-release fishing should be banned because of its supposed cruelty to animals. However, independent of the neurobiological argument, our results indicate that under catch-and-release conditions similar to those tested, fish are neither suffering nor particularly stressed. Catch-and-release fishing is a management tool that will help ensure maintenance of the quantity and quality of overexploited sport fish populations in the United States well into the future. Improved education programs about the relatively benign effects of catch-and-release fishing as a fishery management practice would be beneficial to anglers and the nonfishing public alike.

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